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2900-350-1 Copy No. _____

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Information Note of Project MICHIGAN

MEASUREMENT OF LASER OUTPUT BY LIGHT PRESSURE

CATALOGED BY ASTIA
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May 1962

U. S. Army Signal Corps, Department of the Army, Contract DA - 36-039 SC - 78801

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MEASUREMENT OF LASER OUTPUT BY LIGHT PRESSURE

The use of the laser oscillator in physical experiments requires the measurement of the output radiation. In such measurements, as they are currently made by the authors and other researchers (Reference 1), a blackened cone serves as a simulated blackbody absorber. Absorption of the energy of the laser pulse causes a temperature rise which can be measured by a platinum resistance, thermocouple, or thermistor. If the mass and specific heat of the cone are known, the absorbed energy can be calculated.

This method has proved highly successful for energies from a few hundredths of a joule to perhaps five joules. But for higher energy pulses the accuracy and consistency fall rapidly, because of incomplete absorption and deterioration of the absorbing material. It therefore becomes necessary to absorb externally, or else to deflect an accurately known portion of the high energy pulses. Future developments should yield greatly increased energy outputs, which will eventually make this method of measurement impractical.

It is the purpose of this note to demonstrate that a practical system can be constructed to measure the pressure of a laser pulse on a reflecting surface, and hence the total energy of the pulse. By proper selection of coatings, such a surface can be made very highly reflecting, and thus suffer no significant deterioration. If appropriate system characteristics are chosen, there appears to be no practical limitation on the maximum measurable pulse energy.

It should be noted that though the present discussion treats only pulsed output, the method applies equally well to lasers producing c-w output. It appears, however, that these will remain, at least for the present, in the range handled more conveniently by absorption measurements.

Radiation pressure can be conveniently measured by a torsional pendulum (Figure 1). For such a system, the deflection in radians per joule reflected is easily calculated. Since energy per photon = $h\nu = mc^2$, and momentum per

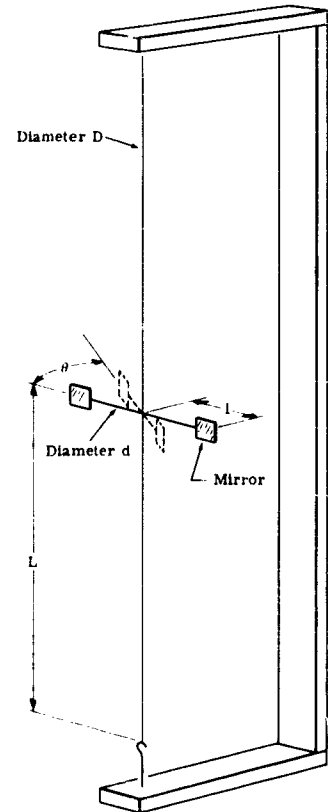


Fig. 1. Torsional Pendulum for Measurement of Light Pressure

photon = $mc = h\nu/c$, the total momentum change per photon = $2h\nu/c$, assuming normal incidence and perfect reflection. The total momentum change per pulse is therefore given by $2h\nu N/c = F\Delta t$, where N is the total number of photons per pulse, F the force exerted on the reflecting surface, and Δt the duration of the pulse. If the period of free oscillation of the torsional system $\tau \gg \Delta t$, then at $\theta = 0$.

$$F\ell = (2h\nu N/c)(\ell/\Delta t) = I\alpha = I(\omega/\Delta t)$$

as $\omega_0 = 0$;

$$\therefore \omega = (2\ell/cI)h\nu N$$

From energy considerations, the maximum kinetic energy of oscillation equals the maximum potential energy stored in the torsional member; that is,

$$(1/2) K\theta^2 = (1/2) I\omega^2$$

from which

$$\theta = (2\ell/c\sqrt{IK})E \quad (1)$$

where E is the pulse energy, K the torsional stiffness, and I the system's moment of inertia.

Dynamic calibration is accomplished by changing the moment of inertia and noting the resulting change in period of free oscillations. Since in general $\tau = 2\pi\sqrt{I/K}$,

$$I_0 = \frac{\Delta I}{(\tau_1/\tau_0)^2 - 1} \quad K = \frac{4\pi^2 I_0}{\tau_0^2} \quad (2)$$

The system must be operated in a vacuum in order to reduce the "radiometer" effect due to heating of the air molecules and reflector. The meanfree path of the air molecules should be at least on the order of the dimension of the system, i.e., centimeters. An order-of-magnitude calculation indicates that $\lambda \approx 10^2$ cm for air at 10^{-4} mm Hg. Thus, a pressure of 10^{-4} mm Hg or less should make any heating effect negligible.

In order to evaluate this method qualitatively, we have constructed such a torsional system; it is shown in Figure 2. The primary concern was to make the system sensitive

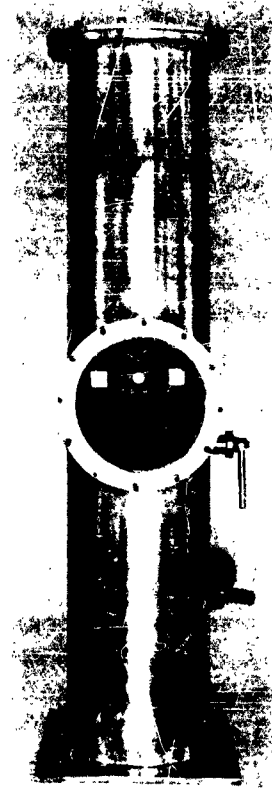


Fig. 2. Experimental System for Measurement of Laser Energy

enough for measurements in the range of the blackened cone. For this purpose, we have chosen a quartz torsional fiber approximately $32\ \mu$ in diameter and 48 cm long ($L = 24$ cm, see Figure 1). The cross arm, a second quartz fiber $250\ \mu$ in diameter and 8.5 cm long ($\ell = 4.25$ cm), supports two silvered mica mirrors weighing 25.5 mg. A silvered cover glass is centrally mounted to allow a readout light beam introducing negligible torque. These values result in an expected deflection of approximately 5.7×10^{-3} radian per joule. The actual sensitivity, taken from period measurements, was found to be 5.2×10^{-3} radian per joule.

In a test of the device, a deflection of 13.9×10^{-3} radian was observed. After allowance for reflections at the glass and mirror surfaces, this indicates that total pulse energy was 3.28 joules. The blackbody absorber measured the output of the same sample, under the same conditions of input energy and sample temperature, at 3.25 joules.

A more sensitive device, using a beam splitter to divert a known amount of each pulse into the blackbody absorber, is being designed. This system will use eddy-current damping, for the most serious difficulty with the present system has been in damping the oscillations between pulses.

In summary, it appears that though this method is impractical with low-energy pulses and current c-w lasers, it does offer an attractive means of handling the extremely high energies which are certain to be produced by future lasers.

The authors wish to express their appreciation to Professors S. K. Clark and C. W. Peters for valuable discussions and suggestions. The excellent technical assistance of F. Alred and M. Smith is gratefully acknowledged.

REFERENCE

1. S. Koozekanani, et al., "Measurements of the Laser Output," Proc. IRE, February 1962, Vol. 50, No. 2, p. 207.

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SURE by J. J. Cook, W. L. Flowers, and C. B. Arnold.
 Information Note of Project MICHIGAN. May 62. 3 p.
 incl. illus.

(Information Note No. 2900-350-1)
 (Contract DA-36-039 SC-78801)
 (Project No. 3D5801001)

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 II. Cook, J. J., Flowers,
 W. L., Arnold, C. B.
 III. U. S. Army Signal Corps
 IV. Contract DA-36-039
 SC-78801
 V. Project No. 3D5801001

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